Global Environmental Change 48 (2018) 206–215

Contents lists available at ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the U.S. Corn Belt

Gabrielle E. Roesch-McNally[a,*], J.G. Arbuckle[b], John C. Tyndall[c]

[a] Northwest Regional Climate Hub, U.S. Forest Service Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331, USA
[b] Department of Sociology, Iowa State University, 303c East Hall, Ames, IA 50011, USA
[c] Natural Resource Ecology and Management, Iowa State University, 238 Science II, Ames, IA 50011-3221, USA

ARTICLE INFO

Keywords:
Climate change
Farmer decision making
Crop diversification
Path dependency
Mixed methods
Multi-level modeling

ABSTRACT

Cropping system diversity can help build greater agroecosystem resilience by suppressing insect, weed, and disease pressures while also mitigating effects of extreme and more variable weather. Despite the potential benefits of cropping systems diversity, few farmers in the US Corn Belt use diverse rotations. This study examines factors that may influence farmers' decisions to use more diversified crop rotations in the US Corn Belt through a parallel convergent mixed methods approach, using a multi-level analysis of Corn Belt farmer survey data (n = 4,778) and in-depth interviews (n = 159). Analyses were conducted to answer questions regarding what factors influence farmers' use of extended crop rotations in intensive corn-based cropping systems and to explore whether farmers in the Corn Belt might use extended crop rotations in response to climatic changes. Findings suggest that path dependency associated with the intensive corn-based cropping system in the region limits farmers' ability to integrate more diverse crop rotations. However, farmers in more diversified watersheds, those who farm marginal land, and those with livestock are more likely to use extended rotations. Additionally, farmers who currently use more diverse rotations are also more likely to plan to use crop rotations as a climate change adaptation strategy. If more diverse cropping systems are desired to reduce climate risks, in addition to reducing the negative impacts associated with industrial agricultural production, then further efforts must be made to facilitate more diverse crop rotations in the U.S. Corn Belt. This may be achieved by adjusting policy and economic incentives that presently discourage cropping system diversity in the region.

1. Introduction

Corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) grown in the U.S. Corn Belt constitute two of the most economically valuable agricultural commodities produced in the United States with broad impacts on the global food supply. Seventy-percent of the Corn Belt agroecosystem is managed to produce corn and soybean commodities through a corn-soybean rotation or continuous corn planting (NASS, 2016). Over the past thirty years, this region has consistently had low crop diversity compared to other regions (Aguilar et al., 2015). This is part of a long-term trend of increased row crop acreage and farm size with less land devoted to diversified cropping systems (MacDonald et al., 2013) and ongoing conversion of grassland, pasture, and marginal lands to row crop production (Claassen et al., 2011; Lark et al., 2015).

Land use practices on farms in the Corn Belt are largely responsible for the hypoxic zone in the Gulf of Mexico due to runoff of nitrogen and phosphorous fertilizer, as well as issues with sedimentation and herbicide toxicity in local and regional watersheds (Donner and Kucharik, 2008; Broussard and Turner, 2009; Hunt, Hill and Liebman, 2017). In addition to these broader environmental concerns, climate change is expected to increase the severity and frequency of crop and animal diseases as well as inducing greater extremes in weather, primarily through increased flooding and drought events (Melillo et al., 2014). These more extreme and variable weather events will likely exacerbate current problems associated with agricultural production in the region, primarily increasing water pollution from sediment loading and fertilizer transport (Broussard and Turner, 2009; Broussard et al., 2012) and is likely to negatively impact crop yields (Takle et al., 2013; Chhetri et al., 2010; Gustafson et al., 2015). Greater diversity of cropping systems may help reduce risks associated with increased weather variability due to climate change and may also drive greater landscape-scale resilience (Aguilar et al., 2015; Gaudin et al., 2015) while balancing multiple goals of "productivity, profitability, and environmental health" (Davis et al., 2012, p. e47149) at the field and landscape scale. In the context of the Corn Belt, extended rotations can include any crop

* Corresponding author.
E-mail addresses: groeschmcnally@fs.fed.us (G.E. Roesch-McNally), Arbuckle@iastate.edu (J.G. Arbuckle), jtyndall@iastate.edu (J.C. Tyndall).

https://doi.org/10.1016/j.gloenvcha.2017.12.002
Received 26 May 2017; Received in revised form 20 October 2017; Accepted 5 December 2017
Available online 23 December 2017
0959-3780/ Published by Elsevier Ltd.

used to diversify the corn-soybean rotation (e.g., small grains, alfalfa, hay, cover crops) integrated over the course of multiple years (Strock and Dalzell, 2014). Over time, extended rotations can also build agroecosystem resilience in fields by reducing weed (Regnier et al., 2015), insect, and disease pressure (Lin, 2011), and can reduce the need for herbicides thus lowering input and application costs for farmers (Hunt et al., 2017). Extended rotations can also reduce the negative effects of fluctuations in market prices and the costs of production (Liebman and Schulte, 2015). Thus, diverse systems can help farmers to manage economic risks over time through integration of internal (e.g., production of feed and forage) and external markets (e.g., commodity markets) (Smith et al., 2008) while also providing broader environmental benefits (Davis et al., 2012; Mulik 2017).

1.1. Regional cropping systems homogeneity

The system of agriculture in the Corn Belt can be characterized as fitting within a productivist paradigm or high-yield production regime (Carolan and Stuart, 2016), which forms the “deep structure” (Geels, 2011) that orients farmer decision making, further contextualized by social, political, economic, and environmental factors at the field, landscape, and human-institutional scale. These structures give rise to path dependency, which Preston defines as the “dependence of future societal decision processes and/or socio-ecological outcomes on those that have occurred in the past” (2013, p.g. 719) and whereby the system itself becomes “dominant and self-reinforcing” (Chhetri et al., 2010, p. 895). This productivist paradigm is thus “stabilized through various lock-in mechanisms, such as scale economies, sunk investment in machines, infrastructure, and competencies” (Geels, 2011 p. 25). This lock-in may ultimately lead individuals to make decisions that are sub-optimal at both an individual and collective level (David, 1985; Ruttan 1997).

As the Corn Belt region continues to trend towards greater cropping system homogeneity at the landscape scale, there has been a concomitant loss of crop and livestock integration and a decreased need for diverse livestock feed and forage (Stuart and Gillon, 2013; Wright and Wimberly, 2013). A number of factors have been implicated in this shift towards greater homogeneity, including environmental factors such as water availability, soil type, topography (Bowman and Zilberman, 2013), and sociopolitical factors such as government commodity program payments (Broussard et al., 2012), crop insurance (Bowman and Zilberman, 2013; MacDonald et al., 2013), biofuel policies (Donner and Kucharik, 2008; Bain and Selfa, 2013; Aguilar et al., 2015; Fausti, 2015), and increased financialization of commodity markets (Clapp, 2012). This intensive agricultural production system “remains strongly reinforced by agricultural markets, legislation, and agribusiness companies that greatly profit from the current system” (Stuart and Gillon, 2013, p.322) and is further guided by the predominant view that monoculture production systems are inherently more productive than more diversified systems (Lin, 2011). As such, private farm-level investments tend to favor production technology that can experience economies of scale and reduced labor needs, such as specialized cropping system technology, including seed and associated chemical technologies (Gould et al., 2004; Vanloqueren and Baret, 2008; Lin, 2011).

Findings from existing literature suggest that there are also some important individual farmer and farm-level factors that influence cropping decisions in highly specialized agricultural regions such as the U.S. Corn Belt. First of all, we understand from behavioral models that attitudes (Fishbein and Ajzen, 2010; Rogers, 1995; Heberlein, 2012) and identity (McGuire et al., 2013; Roesch-McNally et al., 2017a, 2017c) can influence willingness to adopt conservation practices in general. Further, the perception of risk, as well the experience of extreme weather events, can also influence farmers’ conservation decision making (Knutson et al., 2011) as well as actions taken in response to climate change (Brody et al., 2008; Arbuckle et al., 2013b).

Specific to extended crop rotations, farmers have been found to utilize extended rotations as a way to preserve and enhance soil resources in general (Davis et al., 2012; Lehman et al., 2015), particularly on marginal land (Curtforth et al., 2001), but also to reduce climate related risks (Reidsma et al., 2010; Knutson et al., 2011). The use of crop/livestock integration has been found to be an important driver of on-farm diversity (Cutforth et al., 2001; Russelle et al., 2007; MacDonald et al., 2013). Cutforth et al. (2001) found that the slope of farmland, as an indicator for marginal land, and farmers' positive attitudes towards cropping system diversity were positive drivers of crop rotations, while net household income had a negative influence on farmers’ use of crop rotations. A diversified crop rotation is largely compatible with many of the different strategies that farmers use to manage financial risk such as the integration of livestock, the use of federal crop insurance, and commodity market diversification; this compatibility is important in the context of whole farm risk management (Bowman and Zilberman, 2013).In summary, the literature points to both structural and individual-level factors that can shape farmers’ production system decisions.

The research presented in this paper builds on these findings by exploring influences and constraints on farmers’ use of extended crop rotations in the Corn Belt, and whether farmers will diversify in response to increased weather variability associated with climate change. We examine three questions regarding the use of diversified crop rotations in the U.S. Corn Belt: what factors influence the use of extended rotations among farmers in intensive corn producing watersheds?; what are the challenges of integrating extended rotations into corn-based cropping systems?; and, how might increased weather variability, associated with climate change, influence farmers’ decisions to use diversified rotations in their cropping systems? This study employs a parallel convergent mixed methods approach that includes quantitative multi-level modeling of farmer survey responses (n = 4778), coupled with Agricultural Census data aggregated at the six-digit Hydrologic Unit Code (HUC6) watershed-level (NASS, 2014a), and qualitative analysis of in-depth interviews (n = 159).

2. Materials and methods

This study utilized a mixed methods approach, using a parallel convergent design for data collection and analysis (Fig. 1). A parallel convergent design allows researchers to collect “different but complementary data on the same topic” (Morse, 1991, p.122). In this study, survey and interview data are examined using separate statistical and qualitative data analysis procedures, then findings are merged in the discussion section to compare and contrast results from these different data sources (Creswell and Clark, 2011). The methods section outlines the quantitative and qualitative data and analysis in separate sections examined below.

2.1. Quantitative data and analysis

2.1.1. Survey data

Survey data were collected through a random sample survey of Corn Belt farmers that was stratified by 22 Hydrologic Unit Code 6 (HUC6) watersheds representing more than half of corn and soybean production in the United States (Appendix A in supplementary materials). The US Department of Agriculture (USDA) National Agriculture Statistics Service (NASS) Census of Agriculture frame was used (USDA, 2012), providing the most complete and up-to-date list of farmers available in the U.S. The sample population was larger-scale corn producers, defined as farmers that operate more than 80 acres of corn and generate a minimum of $100,000 U.S.D. in gross sales/year. The 22 watersheds cover a significant portion of eleven Corn Belt States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin) and are classified as “major crop areas” for corn and soybean according to the USDA (1994).

The survey was administered in February 2012 using a three-wave

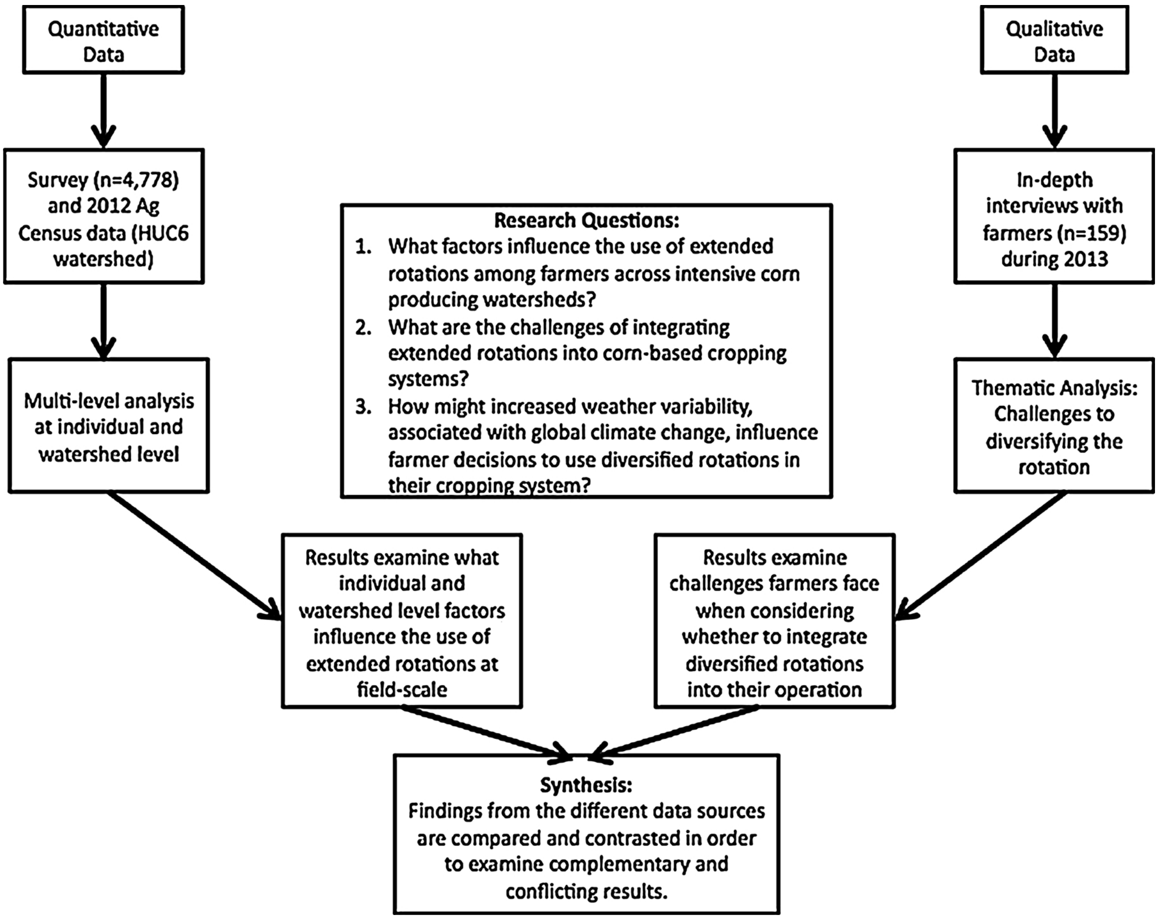

Fig. 1. Mixed methods analysis follows a parallel convergent approach, combining separate qualitative and quantitative data sources and analyses.

Table 1
Eleven level-one (individual level) independent variables were included in the multi-level analyses. Each variable, the associated question/statement from the survey, and the scale that the variable is measured on are also presented, along with information on data source(s). Descriptive statistics include mean and standard deviation (SD).

Variable	Description	Scale	Mean	SD	Source
Dependent Variable					
Diversified Rotations	Farmer uses diversified rotations that include small grains, forages, or other crops on land they own and/or rent	Binary response (0 = No, 1 = Yes)	0.46	0.50	A
Independent Variables					
Individual (level-one) variables					
Productivist	Factor score for productivist identity	Continuous Scale	0.00	0.51	C
Stewardship	Factors score for stewardship identity	Continuous Scale	0.00	0.69	C
All Cattle	Count for all Cattle & Calves *	Continuous Scale	80.94	392.73	B
Crop Insurance	Hectares covered by crop insurance*	Continuous Scale	240.79	282.47	B
Corn Markets	Number of markets farmers produce corn for (six options:commodity, ethanol, livestock, specialty, seed, other)	Continuous Scale	1.95	0.82	A
Water Concern	Summated scale measuring concern about water related risks (Four items: flooding + extreme rains + increased saturation + increased erosion/4)	Four point scale (1 = Not Concerned, 4 = Very Concerned)	2.22	0.69	A
HEL	Hectares of highly erodible land that was planted to crops in 2011 *	Continuous Scale	84.98	244.03	a, b
Diversify_Adapt	Intention to increase use of diversified rotations or not in response to a climate change scenario	Binary response (0 = Stay the same, 1 = Increase)	0.20	0.40	A
Alt_Markets	Statement: “Profitable markets for small grains and other alternative crops should be developed to encourage diversified crop rotations in order to address potential changes in climate.”	Five point scale (1 = Strongly Disagree, 5 = Strongly Agree)	3.61	0.78	A
Education	Highest level of education	Ordinal Scale (1 = Less than high-school, 6 = Graduate degree)	3.27	1.32	A
Farm Revenue	Gross farm revenue (USD)*	Continuous Scale	$457,014	$653,461	B

A. Data from survey of Corn Belt farmers across eleven states in U.S. Corn Belt in 2012 (Loy et al., 2013).
B. Farmer data from the Census of Agriculture that NASS, which conducted the survey for this research, linked to our survey data (NASS, 2014a).
C. Developed using Confirmatory Factor Scores- see (Roesch-McNally et al., 2017a).
* Final model used natural log transformation for variable due to non-normal, right skewed data.

mailing process following the tailored design method for mail surveys (Dillman, 2011). The survey was mailed to 18,813 farmers, followed by a reminder postcard, with a final survey sent to non-responders (Arbuckle et al., 2013a). A total of 4778 usable surveys were returned, for an effective response rate of 26% using the AAPOR response rate calculator. A watershed-level non-response bias analysis comparing respondents and non-respondents identified no meaningful differences (Loy et al., 2013). This suggests that there was no systematic bias between those who responded and those who did not, thus our results can be generalized to the population of larger-scale Corn Belt farmers (Arbuckle et al., 2013a). Additional data were taken from the 2012 Census of Agriculture HUC6 watershed-level reports, described in the source column in Table 1 (NASS, 2014a).

2.1.2. Quantitative analysis

The quantitative data analysis focused on examining factors that influence the use of extended rotations among farmers in intensive corn producing watersheds. Multi-level modeling (MLM) was utilized to evaluate these factors at the individual and watershed-level, by partitioning the variance in these hierarchically nested data (Snjiders and Bosker, 2012). The model includes two levels of variables, measured at the individual farmer-level (level one) and the watershed-level (level two) that help to explain the variability between individuals across the twenty-two HUC6 watersheds. For this analysis, individual data are nested within watershed-level data, therefore all independent variables at level-one (farmers) are centered about their means (i.e., centered within context) to allow for ease of interpretation of intercept values and predictors (Hofman and Gavin, 1998; Enders and Tofighi, 2007). In this way we are able to specify that level-one units (farmers) are nested within level-two units (watersheds). The dependent variable is a binary response variable; therefore, we use a hierarchical generalized linear model (HGLM) to account for the non-normal error distribution associated with dichotomous data (Snjiders and Boskers, 2012). Overall, model assumptions are met; however, three variables were log transformed due to heteroscedasticity in the residuals (Table 1).

The Multi-level model was constructed to examine a dichotomous dependent variable, the use of Diversified Rotations, and includes eleven level-one variables (measured at the individual farmer-level) and four level-two variables (measured at watershed-level) (Table 1). The dependent variable Diversified Rotations measures whether or not a farmer uses diversified rotations in their farm operation, which is a reasonable metric used to assess on-farm diversification within the corn-soybean rotation (Cutforth et al., 2001; Bradshaw et al., 2004). In the survey, farmers were asked if they currently use diversified rotations, such as small grains, forages, or other crops on land they farm, including both owned and rented land.

2.2. Level-one: individual-level variables

Based on an understanding of social, economic, and environmental factors that can influence a farmers' interest in adopting practices that, similar to diverse rotations have both conservation and economic benefits, we include eleven level-one variables to examine their influence the use of extended rotations amongst farmers in the Corn Belt (see Table 1 for a detailed description of level 1 variables).

Because variation in farmer identities, specifically farmers who have more productivist goals (e.g., maximizing yield and profits) versus a more stewardship orientation (e.g., maximizing soil and water conservation goals), has been shown to be associated with different types of farming practices and strategies (Burton, 2004; McGuire et al., 2013; Roesch-McNally et al., 2017a), we employ two variables to measure farmer identity, Productivist and Stewardship, which were developed using Confirmatory Factor Analysis (see Roesch-McNally et al. (2017a) for variable construction).

Diversification broadly defined can also be an important risk management strategy for farmers (MacDonald et al., 2013; Morton et al., 2015), therefore we included three variables that measure different ways that farmers might diversify their economic risks. The variable All Cattle measured the total number of beef cattle, including feedlot and cow-calf operations. A second variable measured the total number of hectares insured using federal crop insurance (Crop Insurance). Finally, a total count of the number of corn markets (Corn Markets) that farmers produce corn for (including commodity, ethanol, livestock, specialty, seed, and other) measured corn market diversification.

Environmental vulnerability, including weather-related risks and erodibility, have also been found to influence farmers' management decisions (Cutforth et al., 2001; Knutson et al., 2011; Morton et al., 2015). Two variables were included in the model to assess relationships between environmental factors and farmers' use of diversified rotations. We created the Water Concern variable as a summative scale consisting of four survey questions measuring farmers' level of concern about the risks that water-related extreme weather events pose to their farm operations, including increased flooding, extreme rain events, increased saturation, and erosion (Morton et al., 2017). We include percent of cropland classified as highly erodible land (HEL) because HEL is generally marginal land with steep slopes and other inherent soil properties that make it more vulnerable to erosion.

Diversification of the crop rotation is also promoted as a strategy to reduce climate-related risks (Hatfield et al., 2014). Major threads of behavioral change research (Fishbein and Ajzen, 2010; Rogers, 1995; Heberlein, 2012) conceptualize attitudes toward behaviors (positive or negative) as strong mediators of decisions to change a behavior (or not) or to continue a behavior once a change has been made. We therefore employ two variables, Diversify_Adapt and Alt. Markets, to evaluate the relationship between farmers' attitudes towards diversifying crop rotations to reduce climate related risk and their current use of diversified rotations.

Farmer education level (Education) and gross farm revenue (Farm Revenue) are included as control variables that might influence whether a farm is diversified or not. Farm revenue has been found to have a negative relationship with on-farm diversification (Cutforth et al., 2001). While both education and farm revenue have been found to be significant predictors of conservation behaviors, their sign and effect can vary across models, with differences based on location and practices examined (Knowler and Bradshaw, 2007; Prokopy et al., 2008; Baumgart-Getz et al., 2012).

Table 2
A total of 4 level-two (HUC6 watersheds) independent variables were included in the multi-level analyses. The name of the variable, the associated description and the scale that the variable is measured on are also presented, along with information on data source (s). Descriptive statistics include mean and SD.

Variable	Description	Scale	Mean	SD	Source
CDI	Cropland Diversity Index	Probability	0.63	0.06	B
Change in Cropland Pasture	Percent Change from 2012 as compared to 2002 in total land in cropland pasture.*	Continuous	81.39	4.84	B
Marginal Soils	Percent of the watershed that would be considered marginal.	Continuous	0.17	0.16	D
Extreme Precip.	Median values for extreme precipitation developed for each watershed.	Continuous	0.01	0.00	E

B. Data from 2012 Census of Agriculture (NASS, 2014a)
D. Data for each county from SSURGO database (Loy et al., 2013)
E. Variable constructed using the National Weather Service Cooperative Observer data archive (Loy et al., 2013)
* All percent changes in cropland pasture were negative indicating that across each watershed there was a net decrease in total cropland pasture in 2012 when compared to 2002. However, we flipped the variable so that the percent change was a positive number to ease the interpretation of the quantitative model presented in Table 3.

2.3. Level-two: watershed-level variables

A cropland diversity index (CDI) (Table 2) was developed to quantify the diversity of cropland at the watershed-level (measured at the HUC6-level, also referred to as a watershed basin) following the method outlined by Broussard et al. (2012).[1] For the construction of the CDI we use Agricultural Census data which includes the total cropland area of six different crops: corn, soybeans, small grains (e.g., wheat, oats, barley, and rye), vegetables, fruits/nuts, and all other crops (NASS, 2014a). We used the following equation to develop the CDI:

$$\mathrm{CDI} = \sum\nolimits_{i=1}^{6} \frac{Crop_i^2}{Crop\ \ land^2}$$

CDI is a measure of cropland diversity for each watershed. The numerator, *Crop*, was the number of hectares of a specific crop type *i* within each watershed, and the denominator, *Cropland*, was the number of total hectares for all cropland in that watershed. A CDI score represents the probability that two randomly selected but adjacent hectares of land would be planted to different crops. A CDI score of 0 represents a zero chance that two adjacent hectares would have different crops as compared to a CDI of 1, which would mean a 100% chance of two hectares having different crops on adjacent hectares.

The Change in Cropland Pasture variable was included to measure the conversion of land from pasture and grassland into crop production. This variable was constructed using Agricultural Census Data based on the percent change between 2002 and 2012 in total land designated as "cropland pasture." The USDA defines cropland pasture as land in long-term crop rotation, which can also include hectares of crops that are hogged or grazed but not harvested.

A third variable was developed (Marginal Soils) to assess whether the proportion of land in a watershed that is considered marginal might be associated with greater crop diversity at the farm level. Marginal lands are determined by using the Natural Resource Conservation Services land capability class system with classes 1–4 considered arable and classes 5–8 as mostly suitable for pasture or rangeland. This variable was computed by summing the land capability class acreages for classes ≥ 4 for each county and creating a proportion of all marginal hectares in the county (Loy et al., 2013). Median values were then computed for the watershed.

Given that crop diversification can be considered to be a climate change adaptation strategy, a measure of the relative incidence of extreme weather at the watershed-level was included. The variable Extreme Precip measures number of days during the five-year period (2007–2011) preceding the survey when the daily precipitation exceeded the 99th percentile of daily precipitation, relative to the forty-year period from 1971 to 2011 (Loy et al., 2013).

2.4. Qualitative data and analysis

Qualitative data were also collected to complement the survey data to better understand the drivers of diversity in the U.S. Corn Belt. Data were collected through semi-structured in-depth interviews with 159 farmers across nine states: Illinois (9 interviews), South Dakota (14), Missouri (16), Ohio (18), Indiana (20), Iowa (20), Minnesota (20), Michigan (20), and Wisconsin (22). Interviewees were mid- to large-scale corn and soybean farmers who were purposively recruited from land grant extension and affiliated agricultural conservation networks in each state. A primary rationale for recruiting these farmers was to reach individuals who had some experience or familiarity with diversified rotations as well as major soil and water conservation practices (e.g., no-till, cover crops) and who may have surmounted barriers associated with these practices.

The interview protocol focused on farmer responses to questions about crop diversification in the context of increased weather variability and whether they would consider diversifying their production system, primarily on land that they consider to be marginal. Marginality was not explicitly defined for farmers; however, during the course of the interviews, farmers discussed the concept of marginality as land that was less suitable for corn-soybean production because of diminished productivity and/or greater soil erosion potential.

The interviews were digitally recorded and transcribed verbatim. Analysis of interview transcripts was conducted in NVivo 10 using a grounded theory approach (Charmaz, 2006). Our analytical procedure utilized an iterative coding method following an open, axial, and selective coding procedure (Corbin and Strauss, 1990). Through an iterative coding procedure aimed at exploring constraints and possible facilitators of more diverse crop rotations, the data were coded into six thematic categories, which include "Corn is King", Lack of Markets, Benefits of Crop Rotation, Loss of Livestock, High Land Costs, and Responding to a Changing Climate. Further examination of these categories is explored in the results section. Theoretical memos were written throughout the coding process in order to explore the relationships between categories and to develop conceptual richness (Charmaz, 2006) and were discussed with the author team to reach agreement about coding accuracy and completeness. As suggested by Prokopy (2011), direct quotes are included in order to increase transparency.

3. Results

3.1. Quantitative analysis

Utilizing a random intercepts model following a procedure to construct a MLM, we found several level-one variables associated with farmers' use of diversified rotations (Table 3). This random intercepts model allows for watershed variation in whether farmers use diversified rotations while introducing farmer-level and watershed-level variables that help to explain why differences might exist between farmers' use of diversified rotations across the 22 HUC6 watersheds. We assessed a best fitting model, which described most of the unexplained variation between watersheds (See Appendix B in supplementary materials). We found that farmers with cattle in their operations (All Cattle) and those who farmed more hectares of highly-erodible land (HEL) were more likely to use diversified rotations. Those farmers who had positive attitudes towards diversified rotations as a climate change adaptation strategy (Diversify_Adapt) were also more likely to report current use of diversified rotations on the land that they farm. Additionally, farmers who agreed with the notion that profitable markets for small grains and other alternative crops should be developed as a climate adaptation tool (Alt_Markets) were also more likely to have diversified rotations. The only variable with a significant negative relationship at the first-level of analysis was Farm Revenue. Therefore the model suggests that as farmer revenues increase, the less likely a farmer is to use extended rotations on their farms.

Two-variables including the CDI and Change in Cropland Pasture, measured at the watershed-level, were significant, and help to explain farmers' use of diversified rotations at the individual-level and between watersheds. The Cropland Diversity Index, or the probability that two adjacent fields will also have two unique crops, had a strong and positive influence on whether individual farmers used diversified rotations. However, the converse is true for Change in Cropland Pasture, with a negative influence on whether farmers use extended rotations on their farm. This means that in watersheds that had more land in Cropland Pasture was converted or planted to row crops, individual farmers were less likely to have diversified crop rotations. In short, as a watershed loses cropping system diversity (and pasture that could be utilized for livestock), the less likely a farmer is to have more diversified

[1] Broussard et al. (2012) use a modified Simpson's Diversity Index (Simpson, 1949) and use relevant cropland hectares for: barley, corn, cotton, hay, oats, rice, sorghum, soybeans, and wheat to construct their Cropland Diversity Index.

Table 3
Fixed effects are presented for the best fitting model, entries show parameter estimates (standardized logit coefficients) and standard errors (SE).

Fixed Effects Model (n = 2316)		
Variables	Coefficients	SE
Fixed Effects:Level-1		
Intercept	0.29**	0.10
Productivist	−0.18	0.10
Stewardship	0.04	0.07
AllCattle	0.34***	0.02
Crop Insurance	−0.01	0.02
Corn Markets	0.11	0.06
Water Concern	−0.04	0.07
HEL	0.07**	0.02
DiversifyAdapt	0.36**	0.12
Alt. Markets	0.43***	0.07
Education	−0.04	0.04
Farm Revenue	−0.24**	0.07
Fixed Effects: Level-2		
CDI	5.92**	2.17
Change in Cropland Pasture	−0.08***	0.02
Marginal Soils	0.57	0.94
Extreme Precip	63.62	46.67

** $p < .01$.
*** $p < .001$.

rotations.

3.2. Qualitative analysis

The primary themes developed through analysis of the qualitative data were data were "Corn is King", Lack of Markets, Benefits of Cropping Systems Diversity, Loss of Livestock, High Land Costs, and Responding to a Changing Climate (Table 4). These six categories emerged from the inductive approach used to analyze the data. In the context of the interviews, farmers discussed extending the rotation through use of specific crops, including cover crops (30), hay/other grasses (28), small grains (27), wheat (24), and alfalfa (20) (the number of farmers discussing each crop type included in parentheses), in addition to more general discussions about the need for a "third or fourth crop" in the rotation.

3.2.1. "Corn is king"

During the in-depth interviews with farmers, many of them discussed the historical context of the Corn Belt, which used to be much more diverse with alternative crops a much more common component of the rotation. Farmers often discussed how they experienced the trend towards increased specialization, emphasizing personal history and observations of the transition to more corn–corn (i.e., continuous corn) and corn-soybean rotations during their lifetime. Many farmers noted that they had grown up in a very different system of production, as exemplified by an Iowa farmer who contrasted the current system of big equipment and animals in confinement with "the diversified ag[riculture] which I grew up on, with the couple hundred acres and diversified, hogs, cows, that kind of stuff." The predominance of the corn-based cropping system seemed to affect the way that farmers thought about the economic viability of alternative crops, as many of the farmers' interviewed did not believe that diversified rotations were as profitable compared to corn and soybean systems. Yet, many of the farmers were interested in how crop diversification might reduce their financial risks by allowing them to access more diverse markets, a benefit explained by a Wisconsin farmer who said,

Monoculture cropping systems, I do believe will, invariably, fail. And we need to have more research into diversifying our cropping mix. When you look at the European model of farming, it's so much different than [ours]…But a lot of European farms are very well diversified…I mean, that their revenue sources are multiple compared to the standard corn/soybean farmer in the United States who has two shots at income.

This farmer expressed an important reflection on how the limitations of the current cropping system that privileges corn and soybean commodity production can impact farmers' ability to generate diverse streams of revenue from their farm operations. Many of the farmers who value diversity already had more diversified rotations but were discouraged that the current system is overly focused on corn and

Table 4
Key qualitative categories/subcategories are presented with the total number of farmers discussing the item (out of 159 farmers), a category description and an illustrative quote.

Category/Subcategory	No. of farmers discussing	Description	Illustrative Quote
"Corn is King"	100	Discussion of the ways the corn-based system predominates and limits diverse rotations	We used to rotate, years ago, with oats. Our potato rotation was potatoes, oats, and alfalfa. And the alfalfa, we would plow down… But [now] we just don't. And corn is king, unfortunately. (WI farmer)
Lack of markets	61	Discussion of how the lack of markets for alternative crops limits diverse rotations	Well, if small grains were more competitive and viable, I would put those in the rotation. Beyond that, you know, maybe a little more conservation minded but, right now, they don't compete. They just don't compete. Even soybeans don't compete right now. That's why you see so much corn. (MN farmer)
Benefits of cropping systems diversity	42	Discussion of benefits of crop rotations, despite not always having a clear idea about what the rotation might be	A long-term goal of mine would be diversity… I was having a hard time thinking of another crop to grow on my marginal land. Well is there some kind of diversity that I haven't even have thought about for my farm that would make it productive? (OH Farmer)
Loss of livestock	24	Discussion of the ways that crop/livestock integration has disappeared from region	We farrowed to finish, too. And we were better off financially and from an environmental standpoint in just taking care of our resource that we'd been given… Now, you live or die by two crops. And, ultimately, I don't feel that this is sustainable. (WI Farmer)
High land costs	19	Discussion about the high cost of land, particularly rented land- driving farmers to produce more corn and soybeans due to historically high land prices	I only own 40 acres and the rest of it is all rented and so much of it is, you know, the landlord has to be on board for that. So I have one piece right now that there's a corner that I cannot get into almost every single year. I cannot plant it cause it's too wet and I approached him about, hey, let's just put an acre into CRP here. And he goes, oh, no, we don't need to do that. You know? So he'd rather get [money for] an acre of rent on that one from me. (MN farmer)
Responding to a changing climate	12	Discussion of diversifying the crop rotation in response to a changing climate	Oh, climate [change]… I'm more excited about it. I mean, I'm planting barley… and, you know, do I double crop? If I can take advantage of the change in climate, that's great. I'm trying to experiment and find out how to do that. (IN Farmer)

soybean commodities, according to a Minnesota farmer, "I'd like to see more crops in a rotation. I'd like to see more food-producing crops rather than commodity crops that are not necessarily used directly for food." Each farmer, in a variety of ways expressed this notion that "corn is king" in the region despite the historical diversity of the region, or even their preferences for seeing greater diversity on the landscape.

3.2.2. Lack of markets

Many farmers discussed the lack of markets for alternative crops that could be used to extend their rotation. One South Dakota farmer noted, that "Actually, I would love to grow other crops. I mean, I would love to have more than two crops in rotation." However, this farmer noted that limited markets and lack of economic profitability prevented them from growing other crops. Multiple farmers noted that markets for wheat, canola, and hay had disappeared from their regions. One farmer from Minnesota said, "I would consider alternative crops. I've tried wheat. Unfortunately, our market here's almost nonexistent…Plus, wheat doesn't return as much as corn and soybeans." In this way, many farmers talked about the alternative markets as possibilities but typically noted that they are not economically viable, especially relative to corn and soybeans.

While lack of markets, in general, was typically discussed in the context of barriers to extending the rotation, some farmers were interested in the potential for biomass markets, although such markets are currently very limited. This point was well-articulated by an Indiana farmer who said, "I don't see a market for [other crops] that I can use that [particular] farm for in [the span of] a one-year cash flow term that would be beneficial to me or my family at this time. Now there may be things down the road with cellulosic ethanol, you know?" A number of farmers expressed interest and expectations for a future cellulosic ethanol market (e.g., wood or grass-based feedstock) that would provide an economic incentive for growing a more diverse set of crops, but most did not believe those markets would be available in the near term.

3.2.3. Benefits of cropping systems diversity

Some farmers believed that integrating a more diverse rotation would help them to achieve broader conservation goals for their farms, noting that more diversified rotations have multiple benefits. However, a number of farmers struggled to identify an alternative crop that might work in their rotation. According to an Iowa farmer, determining how to integrate more diversified rotations without livestock is a challenge,

> If I was starting over again…I would probably go back to more of a 3-way rotation…we used to have a lot of hay and oats. And most livestock guys still have that same system. I always thought that if we had corn, beans, and wheat or something like that to help break up the cycle more, that it would be better for the environment. But what's that third thing going to be?…But, what should I say, unless you're a livestock person, then you're not going to probably break up your rotation to that extent.

A number of farmers expressed that the corn-based cropping system is flawed, particularly a system of continuous corn production that has done away with rotations altogether, as described by an Iowa farmer,

> I think that our intense cropping situation has more of an adverse effect on our conservation than anything else. Growing up, everybody had livestock and there was a lot more hay and oats and things like that to…[which helps to] keep the soil where it belongs.

Some farmers argued that this intensive monoculture system causes environmental and economic challenges but most were uncertain about potential alternatives and whether they could diversify their cropping system and still maintain productivity and profitability of their farm enterprise. A farmer from Ohio expressed this challenge well,

> A long-term goal of mine would be diversity…I was having a hard time thinking of another crop to grow on my marginal land. Well, you know, is there some kind of diversity that I haven't even have thought about for my farm that would make it productive?

Farmers expressed an interest in diversifying their rotation yet they struggled with identifying viable crop alternatives. Some farmers found it difficult to imagine greater cropping systems diversity in their corn-based cropping system despite a general interest in extending their rotation. In general, farmers who discussed benefits of diversity also articulated the challenge of making tradeoffs with the benefits of crop diversity and profitability. According to a Michigan farmer, "I think that [more diverse rotations] would be a helpful thing to this farm but, acres per dollars, that type of thing, right now [with the low] profit margins and so…we're bringing in more [land] with the corn-soybean rotation."

3.2.4. Loss of livestock

A number of farmers focused specifically on the loss of crop/livestock integration as a reason why there are fewer crops in their rotations or in the region as a whole. Farmers typically discussed how their farm had once had livestock, but they often described that they are now just "crop farmers" and indicated an unwillingness to go "back in time." Others noted that more diversified rotations would be more feasible if livestock production were more viable in their region like it used to be. This was expressed by a farmer from Illinois who said that some of their land "used to be pasture but, … the [financial] risk of livestock has just been increasing so much that, you know, that the livestock part of it has disappeared." Additionally, this disappearance was fostered by patterns of investment in cropping systems (e.g., through tile drainage, irrigation). This is articulated by a Michigan farmer who said, "We have a beef [feeding] operation…I have daughters that wanted me to turn some of this land into pasture but I don't tile [drain] ground to turn it into pasture."

However, some farmers' noted that through specialization and concomitant loss of crop/livestock integration, they have lost some of their financial resilience, according to a Wisconsin farmer, "We farrowed to finish [hogs], too. And we were better off financially and from an environmental standpoint in just taking care of our resource that we'd been given [by having livestock]…Now, you live or die by two crops. And, ultimately, I don't feel that this is sustainable." Farmers consistently expressed frustration with the challenge of making livestock work in an era when "corn is king" and therefore they felt that livestock integration no longer made much financial sense in their personal operation, despite the fact that many farmers perceived that there were financial and environmental benefits of having livestock in their operation to diversify their portfolio.

3.2.5. High costs of land

Farmers occasionally brought up high costs of land as limiting their use of extended rotations. In particular, the land values were most commonly discussed in relation to markets for rented cropland (i.e., "cash rents"). Farmers suggested that the crops produced on their rented land needed to be profitable on a yearly basis to pay cash rents. This was emphasized by an Iowa farmer who said, "Rent keeps going up and [you] can't afford to put hay ground on rented ground." This was further affirmed by a South Dakota farmer who expressed a desire for a more diversified crop system, but the barrier of high land costs, accompanied by the challenge of limited markets, constrained his choices,

> I would like to include a small grain crop in the rotation so I can better use cover crops. But, at this point in time, I don't think that's practical from an economical point of view. I mean, we look at our land costs and, you know, the cost of buying land and the returns from the different crops and so on and, frankly, the other way I've considered it is, and I haven't done it, but [is to] go to a monocrop…to a continuous corn [system].

The conversation about high costs of land, in some cases, was tied directly to a conversation about what landlords might want to see on their rented ground. This often led farmers to focus on maximizing annual profits/hectare, which can favor a corn–corn rotation because of the historically high prices for corn commodities in recent years. A farmer from Illinois, when discussing his rental ground, said that "you

push the pencil and do the math on your corn and, you know, in most cases, corn on corn on dark dirt usually pencils out to be the way to go." That farmer was actually talking about trying to integrate soybeans into his rotation but felt that corn–corn was the most economically sound choice. In this way, farmers may want to extend their rotation yet they find that they face financial challenges if they shift too far away from a corn–corn or corn-soybean rotation.

3.2.6. Responding to a changing climate

A few farmers discussed diversified rotations as a viable strategy for capitalizing on climate change. Often they discussed this in the context of changing climate patterns, envisioning a time when they might be producing different crops driven by changes in the climate. According to an Illinois farmer, "maybe I'll start [growing] wheat. You can't grow wheat here now…Maybe [in the future] we'll be growing more wheat. Maybe the climate will change." However, a number of them discussed minor modifications that they had made due to recent weather events, including planting soybeans instead of corn due to the late spring rains or planting wheat during dry years. In general, increased weather variability did not appear to influence farmers to shift their production far beyond the corn-soybean system. Most farmers noted that increased weather variability might encourage them to plant soybeans instead of corn in certain years, according to a Wisconsin farmer who said, "we might have a few more beans in the rotation so that we [have] less acres of continuous corn."

Overall, few farmers explicitly discussed using crop rotations as a way to minimize climate related risks. However, the use of cover crops was a clear strategy for diversifying the rotation and conserving soil resources that some farmers saw as a way to integrate greater diversity in their cropping mix while also mitigating risks from more extreme weather events. According to a South Dakota farmer, extreme weather events are encouraging them to think more about integrating cover crops, particularly if they can help protect their soil resources, "I would guess that [climate change] means bigger rainfall events so the impetus to keep soil in place and to do cover crops is probably going to be something that we're going to have to pay much more attention to."

4. Discussion

This study provides a current and comprehensive mixed methods analysis that examines the drivers of diversified crop rotations in the U.S. Corn Belt as a management practice that has the potential to facilitate greater economic and climate resilience in the Midwest. We sought to better understand what social, economic, and environmental factors, at the individual and watershed-scale, influence farmers' use of extended rotations. The results from the mixed-method analysis suggest that both farmer and field-level characteristics, as well as more structural drivers associated with the productivist paradigm of agriculture in the Corn Belt characterized by path dependency and lock-in, constrain farmers' ability to integrate more diverse crop rotations into their operations.

At the farmer and field level, the quantitative analysis suggests that farmers with livestock and those who farm more marginal land are more likely to use extended rotations. Both analyses affirm the importance of livestock in facilitating the use of diversified crop rotations due, in part, because coupled crop and livestock systems enable livestock to convert plant material into useable food and fiber that has an economic value (Poffenbarger et al., 2017). However, the regional trend in the Corn Belt continues to shift away from crop/livestock integration with more focus on feeding animals in confinement operations (MacDonald et al., 2013; Stuart and Gillon, 2013). Further, the quantitative results suggest that marginal land (e.g., HEL) might also be a motivator for increasing the use of extended rotations, yet the qualitative data suggests that many farmers have found ways to make marginal land more productive for corn-soybean production through changes to their management practices (e.g., adding tile drainage or implementing conservation practices).

Findings from both analyses illustrate that farmers acknowledge the benefits of diversifying their crop rotation as a way to respond to weather and climate related changes. Additionally, farmers who already use diverse crop rotations may be more likely to use extended crop rotations as a strategy for responding to future climate changes, affirming prior research that suggests that farmers are more likely to increase their use of current management practices in response to predicted climate change (Roesch-McNally et al., 2017a). The results of the qualitative data suggest that weather events are not a major driver for greater crop diversity although some believe climate changes may potentially facilitate (or necessitate) adoption of new or more diverse cropping systems. Overall our findings provide evidence that the use of more diverse crop rotations is not likely to be encouraged by climatic factors alone, echoing Bradshaw et al.'s (2004) Canadian Prairie region study finding that crop diversification as a climate change adaptation strategy, was unlikely to occur due to the increasingly prevalent trends towards specialization at both the farm and regional scale.

Taken together, our findings suggest that the productivist paradigm in the Midwest and associated path dependency and associated lock-in has reinforced the corn-based cropping systems, thus limiting options for farmers to increase their use and adoption of diverse crop rotations evidenced in the qualitative findings from this study, exemplified by notions that "Corn is King" in the Midwest. Within this corn-soybean cropping system, farmers typically must adopt associated technologies, such as improved seed varieties and attendant chemicals, which require more specialized farm equipment and greater reliance on external inputs (Gould et al., 2004). These investments represent sunk costs for farmers who are operating within the corn-based cropping system. In the quantitative findings, farmers with higher revenues were less likely to adopt more diverse crop rotations, signaling that those farmers doing financially well within the current production system, perceive little incentive to change their rotations even if, as found in the qualitative data, they see that diversified rotations have both economic and environmental benefits. Qualitative data suggest that lack of available markets and high costs of land also limit farmers' ability to shift to more diverse cropping systems and therefore many feel trapped by the current system or unable to identify viable alternatives that they could adopt on their farm.

Both the qualitative and quantitative analyses provide evidence of this path dependency and associated lock-in through the emergence of a few key findings. In particular, the significance of the Cropland Diversity Index indicates that a more diverse watershed is a good predictor of whether an individual has diverse rotations. Additionally, as more land within a watershed designated as Cropland Pasture is converted to row crops that are harvested on a yearly basis, the less likely a farmer will have diversified crop rotations in their operation. Indeed, greater diversity at the watershed level may facilitate diverse crop rotations at the individual level due to the presence of alternative markets (e.g., small grains or feed) and associated technological and market infrastructure. Close proximity of other farmers who have diversified rotations may also influence farmer behavior due to the importance of observing neighbors when considering adoption of new practices (Rogers, 1995; Roesch-McNally et al., 2017a, 2017b). However, the loss of Cropland Pasture might indicate the same relationship but in the opposite direction, as more land is converted to crop rotations, primarily two-crop rotation, the more likely individuals are to reduce their own use of extended rotations, therefore neighbors might also be influencing each other by reinforcing the logics of specialization and homogenization. However, the significance of the CDI variable may also be picking up on ecological constraints at the watershed level, such as topography, slope, soils and climate, which may also help to predict the use of extended rotations (Cutforth et al., 2001). The qualitative data suggest that financial incentives that encourage alternative cropping systems, such as markets for biomass or small grains such as oats, might enable farmers to incorporate more diverse rotations on their

farms; however, given the high input costs (NASS, 2014b), particularly high cash rents (Secchi et al., 2008) and the need for yearly profitability, these incentives will need to be competitive with commodity and cropland rental markets.

Path dependence within the corn-based cropping system in the U.S. Corn Belt illustrates an example of how intensive agricultural systems, characterized by consolidation, increased specialization and concomitant economies of scale (as found in many commodity producing regions in the world), can limit farmers' ability to shift their production systems towards alternatives due to the "macro-scale historical, socioeconomic, and political context" of their region (Blesh and Wolf, 2014, p.4). Changing cropping systems would also require high up-front costs to invest in new equipment and associated inputs (Isbell et al., 2017) and may also require changes to existing incentive structures (e.g., crop insurance program as outlined in the U.S. Farm Bill) as well as reducing technology and information barriers at the farm and regional scale (Mulik, 2017). This context of "lock-in" may ultimately limit farmers' ability to respond appropriately to a changing climate (Chhetri et al., 2010) or to take advantage of superior technologies or practices (Cowan and Gunby, 1996; Vanloqueren and Baret, 2008).

5. Conclusions and policy implications

Those calling for greater cropping system diversity argue that greater diversity can build agroecosystem resilience (Lin, 2011; Davis et al., 2012), particularly in the face of a more extreme climate regime (Hatfield et al., 2014). Diversified cropping systems that incorporate greater plant diversity may enable actors operating in intensive agricultural systems to reduce their reliance on conventional inputs while also optimizing yield and ecosystems services thus providing both private benefits to farmers as well as public goods to society (Isbell et al., 2017). Despite these potential farm and landscape scale benefits, our findings suggest that integrating greater crop diversity in the region will be difficult because the current technological trajectory is moving towards greater specialization rather than diversification, and subsequent field- and landscape-scale homogeneity rather than heterogeneity. The results of this study suggest that the promotion of diverse rotations will require major cross-scale policy solutions (Cash et al., 2006) that better link efforts to diversify cropping systems across spatial and human institutional scales. However, policies aimed at bringing about a change will be challenged to overcome the status quo (Cowan and Gunby, 1996) and existing policies that have helped to shape the current system and reinforce path dependency.

If facilitating more diversified cropping systems and slowing or reversing the long-term trend towards landscape-scale cropping systems homogeneity is an important goal (Rotz and Fraser, 2015), then social, political, and economic institutions will need to be adjusted to encourage greater crop diversity at the farm and watershed scale (Mulik, 2017). Some strategies for altering this institutional context and reducing barriers to a more diverse cropping system in the U.S. Corn Belt might include:

1. Increasing financial incentives that help producers to overcome upfront costs associated with investing in new cropping systems/alternative crops, which could be facilitated through financial programs delivered by conservation programs (e.g., Conservation Stewardship Program) or changes to crop insurance incentives that would enable more diverse crop rotations and disincentivize monoculture production.
2. Investing in programs that will drive the development of alternative markets (e.g., next generation biofuels that use more diverse feedstocks) which may require new research and development (Vanloqueren and Baret, 2009) and processing infrastructure to help create viable alternative markets for small grains or pasture-raised livestock.

Recent declines in crop prices for corn and soybean commodities (Schnepf, 2017) and broader concerns about farm program funding, coupled with farmer interest in diversifying their rotation, may provide an impetus to diversify the Corn Belt agroecosystem. However, proactive policy and market development will also be needed to facilitate a sustainable transition to a more diverse agroecosystem in the U.S. Corn Belt.

Funding statement

This work was supported by the Sustainable Corn and Useful to Useable Project funded by the U.S. Department of Agriculture-National Institute of Food and Agriculture [Award No.'s 2011–68002-30190 & 2011–68002-30220]

Acknowledgements

We would like to thank the many farmers who participated in our survey as well as those who participated in-depth interviews during 2012–2014. Additionally, we would like to thank Dr. Diana Stuart for her helpful review of this document, in addition to reviews from Drs. Lois Wright Morton, Carmen Bain and Lisa Schulte-Moore.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gloenvcha.2017.12.002.

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